The Giant Monopole Resonance in the $^{112-124}$Sn Isotopes and the Symmetry Energy Term in Nuclear Incompressibility

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Abstract

We have investigated the isoscalar giant monopole resonance (GMR) in the Sn isotopes, using inelastic scattering of 400-MeV α-particles at extremely forward angles, including 0°. A value of -550 ± 100 MeV has been obtained for the asymmetry term, K_τ, in the nuclear incompressibility.

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Incompressibility of nuclear matter remains a focus of experimental and theoretical investigations because of its fundamental importance in defining the equation of state (EOS) for nuclear matter. The compressional-mode giant resonances – the Giant Monopole Resonance (GMR) and the isoscalar giant dipole resonance (ISGDR), an exotic compressional mode of nuclear oscillation – provide a direct means to experimentally determine the nuclear incompressibility. From recent measurements on the GMR and the

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ISGDR, a value of $K_\infty = 240 \pm 10$ MeV has been obtained, consistent with results of recent theoretical results in both relativistic and non-relativistic frameworks [1,2,3].

The asymmetry term, K_τ, in the expression for nuclear incompressibility is important because it is critical to determining the radii of neutron stars, and also in understanding the compressional-mode resonances in very neutron-rich nuclei, the primary focus of investigations at current and forthcoming radioactive ion beam facilities. In particular, it has been shown that the radius of a 1–1.5 $M_\odot$ neutron star is mostly determined by the density dependence of the asymmetry-energy term [4,5].

In this presentation, we report on new measurements on GMR in the even-A Sn isotopes. The experiment was performed at the ring cyclotron facility of the Research Center for Nuclear Physics (RCNP), Osaka University, using inelastic scattering of 400-MeV α particles at extremely forward angles, including 0°. Details of the experimental techniques and the data analysis procedures have been provided previously [6]. Sample background-free "0°" inelastic spectra are presented in Fig. 1 (a). Giant monopole resonance strength distributions were obtained for all Sn isotopes under study using a multipole-decomposition analysis (MDA) [6]; Fig. 1 (b) shows a sampling of MDA fits to angular distribution data. Table I lists the centroid energies and widths extracted from Lorentzian-peak fits to the extracted GMR strength distributions, as well as the "standard" moment-ratios typically used in theoretical calculations.

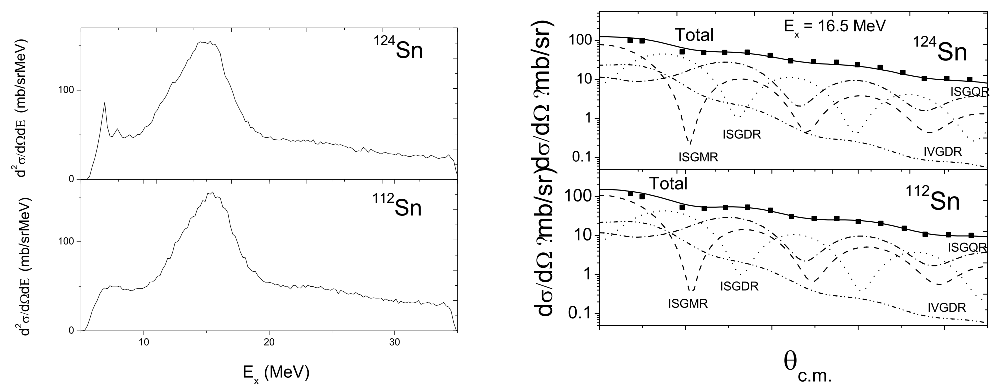

Fig. 1. (a) 0° inelastic scattering spectrum for ^{112}Sn(α,α') and ^{124}Sn(α,α') at E_α= 400 MeV. (b) Angular distribution of 1-MeV bins centered at E_x=16.5 MeV for ^{112}Sn(α,α') and ^{124}Sn(α,α'). The solid squares are the experimental data and the solid line is the MDA fit to the data. Also shown are the contributions to the fit from L=0 (dashed line), L=1 (dotted line), L=2 (dash-dotted line) and IVGDR (dash-dot-dotted line).

Table 1
Lorentzian-fit parameters and moment-ratios for the GMR strength distributions in the Sn isotopes.

Target	E_{GMR} (MeV)	Γ (MeV)	m_1/m_0 (MeV)	$\sqrt{m_3/m_1}$ (MeV)	$\sqrt{m_1/m_{-1}}$ (MeV)
^{112}Sn	16.1 ± 0.1	4.0 ± 0.4	16.2 ± 0.1	16.7 ± 0.2	16.1 ± 0.1
^{114}Sn	15.9 ± 0.1	4.1 ± 0.4	16.1 ± 0.1	16.5 ± 0.2	15.9 ± 0.1
^{116}Sn	15.8 ± 0.1	4.1 ± 0.3	15.8 ± 0.1	16.3 ± 0.2	15.7 ± 0.1
^{118}Sn	15.6 ± 0.1	4.3 ± 0.4	15.8 ± 0.1	16.3 ± 0.1	15.6 ± 0.1
^{120}Sn	15.4 ± 0.2	4.9 ± 0.5	15.7 ± 0.1	16.2 ± 0.2	15.5 ± 0.1
^{122}Sn	15.0 ± 0.2	4.4 ± 0.4	15.4 ± 0.1	15.9 ± 0.2	15.2 ± 0.1
^{124}Sn	14.8 ± 0.2	4.5 ± 0.5	15.3 ± 0.1	15.8 ± 0.1	15.1 ± 0.1

The incompressibility of a nucleus, K_A, may be expressed as:

$$K_A \sim K_{vol}(1 + cA^{-1/3}) + K_\tau((N - Z)/A)^2 + K_{Coul}Z^2A^{-4/3} \quad (1)$$

For a series of isotopes, the difference $K_A - K_{Coul}Z^2A^{4/3}$ may, thence, be approximated to have a quadratic relationship with the asymmetry parameter, [(N-Z)/A]. Such a quadratic fit, using the customary moment ratio $\sqrt{m_1/m_{-1}}$ for the energy of the GMR in calculating the K_A, gives K_τ = -550 ± 100 MeV; the quoted uncertainty includes the uncertainties in the values of K_A and K_{Coul}, as well as the statistical uncertainties from the fitting procedure.

From the data on the compressional-mode giant resonances, we now have "experimental" values of both K_∞ and K_τ which, together, can provide a means of selecting the most appropriate of the interactions used in EOS calculations. For example, this combination of values for K_∞ and K_τ essentially rules out a vast majority of the Skyrme-type interactions currently in use in nuclear structure calculations [7]. This is borne out by Fig. 2 in which are plotted the values of K_∞ and K_τ for a number of interactions used in both relativistic and non-relativistic calculations. It is clear that nearly all of them fall outside of the "acceptable" region defined by the values obtained in our measurements, leaving a challenge for the theorists to construct appropriate interactions that meet this criterion.

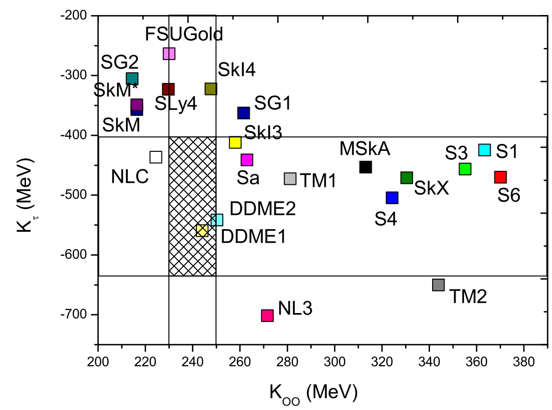

Fig. 2. Values of K_∞ and K_τ calculated from the parameter sets of various interactions as labeled [7]. The vertical and horizontal lines indicate the experimental ranges of K_∞ and K_τ, as determined from the GMR work.

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